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USE OF FRICTION COURSE MIXES IN ONTARIO

MATERIALS INFORMATION

ENGINEERING MATERIALS OFFICE

USE OF FRICTION COURSE MIXES IN ONTARIO

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ABSTRACT

The dramatic increase in the volume and speed of automotive vehicles in the 50s and 60s in Ontario resulted in the need for safer and better quality highways. The increased traffic also created rapid deterioration of frictional and durability characteristics of the road system that was originally designed for lighter traffic. The need to up-grade the urban freeways and to rehabilitate other highways lead to the development of the friction course mixes.

In the process of formulating policy for safer and better quality highways, in 1974 a major installation of 18 test sections of bituminous overlays on one of the heaviest trafficked roads in Ontario was undertaken, and a task force was also set up to review the performance of friction course as well as to make recommendations on their use.

This paper outlines the developments leading to the adoption of a policy of using friction course mixes in Ontario. It discusses the design, construction and results of the experimental sections and the findings of the task force on friction course mixes. The experience gained and the annual program of friction courses are also discussed.

One important finding of the experiment is that the most effective way to improve the level of friction on a wearing course is by using harsh, angular fine aggregates such as traprock or slag screenings and a sufficient proportion of crushed good quality coarse aggregate in the bituminous mixes to maintain the micro- and macrotexture of a surface. These characteristics can best be provided by Open Friction Course (OFC) and Dense Friction Course (DFC) mixtures.

Friction courses are accepted by the Ontario Ministry of Transportation and Communications as the most suitable surface course mixtures for freeways and accident "black-spots". The steady volume of friction course mixes each year verifies this commitment.

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1. INTRODUCTION

The advances in the automobile technology in the 50's resulted in the need for safer and better riding quality roads to accommodate for the high speed transportation. The dramatic increase in the volume of traffic on the roads that was brought about by the increase in the post-war ownership of automobiles and the change to the surface transportation of goods and commodities by trucking contributed to greater challange for the highway engineer to construct and maintain better highways.

Such need was clearly felt on a major multi-lane urban commuter freeway in metropolitan Toronto - the Hwy. 401 Toronto By-pass. The rehabilitation and upgrading of this section of freeway opened up the search for better techniques to improve the driving qualities, as well as for a hot mix resurfacing system that will produce a long wearing surface with good friction properties which will withstand the high volumes of traffic.

This paper outlines the developments leading to the use of open friction course (OFC) and dense friction course (DFC) involving a major installation of 18 test sections, and the findings of a task force on the performance of these friction courses. In addition, the annual OFC and DFC program and the rehabilitation techniques are discussed.

2. BACKGROUND

The implementation of the use of OFC and DFC was sparked by the need to rehabilitate Hwy. 401. Planned, constructed and reconstructed in stages over the past 40 years, Hwy. 401 (Fig. 1), or The MacDonald-Cartier Freeway as it is also called, has become the main artery across Southern Ontario. It runs from the Ontario-Quebec boundary on the east to the Ontario-Michigan boundary on the west, for a total distance of 820 km (510 miles). Commencing in 1947 sections of this major route were constructed to by-pass major centres. In its 50+ km (30 miles.) path through Metropolitan Toronto it combines with Hyw. 427 to become the main commuter east-west route serving a population of three million people. The AADT (average annual daily traffic) for the busiest location is 238,400, with 1800 vehicles per lane, per hour at peak periods over several sections.

2.1 Construction of Hwy. 401 into an Urban Freeway

In the vicinity of Toronto, Hwy. 401 was first constructed as a four-lane divided rural freeway through largely agricultural land. Construction began in 1952, and by 1958 the basic four lane divided

controlled-access highway was completed. It was built as a conventional flexible pavement with gravel shoulders, core type construction and a wide depressed median.

By 1960 the by-pass was being taxed beyond capacity due to the fact that, within a relatively short period of time after completion, numerous residential sub-divisions and industrial areas were constructed adjacent to the freeway which resulted in a major increase in car and traffic volume (Table 1).

The reconstruction of the original facility to a multi-lane, urban commuter, concrete pavement in the vicinity of Toronto took place between 1963 and 1973 when the original four lane asphalt pavement was widened to a twelve lane system of collector and express lanes. Concrete pavement was chosen for the highway since it was assumed to have the best potential for providing a long service life under the anticipated heavy traffic conditions.

2.2 Performance of the Concrete Pavement

It was originally expected that the Portland cement concrete pavement would be maintenance free for 25 years. However, within less than 10 years of construction it was evident that rehabilitation would be required sooner than expected because of emerging problems. The main and earliest problem to develop was the marked increase in the multi car wet weather accident rate. The Ministry tried grooving the existing concrete pavements to improve the frictional properties. That technique, although somewhat effective for a while, created excessive tire noise which was unacceptable to both the driving public and nearby residents. Problems were also encountered with the performance of the joints and transverse cracking began to show up between the joints and spalled areas of varying depth developed at quite a number of joints and cracks.

During the ten year period after the construction of the first section of concrete pavement there was a marked increase in traffic volume over that anticipated as well as a dramatic increase in allowable truck weights and axle loadings (Table 1).

3. DEVELOPMENT OF POLICY FOR SURFACE COURSE MIXES

The low friction condition was created because of the original burlap drag and broom textured concrete pavement surface was severely polished by the heavy traffic and studded tires (banned after 1971). The texture depth

was reduced to about one tenth of what is desirable. The friction value as determined by the ASTM Brake Force Trailer at 100 km/h (62 mph) varied between 19 and 22.

3.1 Bituminous Mix Test Sections

In an effort to determine the best rehabilitation methods for future programs to restore the driving qualities of the concrete pavement, the Ministry designed and placed 18 bituminous overlay test sections in 1974, involving the use of dense and open graded hot mixes, sand asphalt mixes and mastic mixes both with and without asbestos. The emphasis in the evaluation of the test sections was on long term frictional characteristics and improvement of the ride. The other consideration was that the rehabilitation method chosen should be of low cost. The following describes the main points of the experiment:

(a) Test Location and Traffic:

The location for the test sections was on the westbound core lane between Allen Expressway and Jane Street (Fig. 1). The traffic count had increased dramatically from 111,000 AADT in 1967 to 179,000 in 1974 and 260,600 in 1985. The percent truck traffic averaged about 17%.

(b) Layout of Test Sections:

The 18 test sections were placed each 137 m (448 ft.) long and 11.3 m (37 ft.) wide. Sections 1 to 10 and 17 were 38 mm (1-1/2 in.) thick overlays whereas Sections 11 to 16 were only 25 mm (1 in.) and Section 18 consisted of two lifts of 38 mm (1-1/2 in.) each.

(c) Mix Design and Composition:

Recognizing the fact that a surface with good frictional properties must possess sufficient microtexture or harshness (evaluated by PSV per ASTM D3319) and suitable macrotexture or stone projections (measured by ASTM E770 method, ref. 1) , the mixtures were so designed to have various degree of micro- and macrotextures. The test sections included both dense and open graded types of mixes with a variety of coarse and fine aggregate types including traprock, steel slag and blast furnace slag (Table 2).

Test sections 1 to 10 consisted of HL-1 mixes in which the coarse aggregate content was progressively increased to obtain a greater macrotexture i.e. more stone particles at the surface (Fig. 2). The standard HL-1 mix is a dense graded mixture with good quality coarse aggregate (50% retained 4.75 mm sieve) and local fine aggregate. The

modified HL-1 mixes tested are mixtures with good quality fine aggregate (i.e. DFC by definition), or a blend thereof, rather than only the local natural sand.

Mixes in Sections 11 and 12 were sand asphalt mixes using traprock screenings containing small percentages of coarse aggregates and asbestos fiber filler for greater flexibility and impermeability.

Sections 13 and 14 were open graded mixes designed to have high permeability (e.g. > 10^{-5} cm^2, test method ref. 6) characteristics that facilitate rapid drainage of surface water into, and laterally through the surface course layer, i.e. O.F.C. mixes. The mixes used a large proportion (67%) of single size coarse aggregate and a small amount of washed fine aggregate (Fig. 2).

Sections 15 and 16 were also considered as OFC mixes but with 30% coarse aggregate and washed fine aggregate as in mixes 13 and 14. Section 17 was a mix called "Mastiphalt" which is a kind of mastic asphalt derived from the German "Gussasphalt" technology and modified so that the material could be mixed and placed with conventional equipment.

(d) Construction:

Night paving was necessary due to the heavy traffic. The core lanes at the contract location were closed and traffic diverted to the collector lanes via a transfer lane. The construction was problem free, except that normal mixing time was extended for mixes with asbestos due to lumps of asbestos appearing in the mix.

(e) Frictional Performance of Test Sections:

The frictional characteristics were measured using the ASTM brake-force trailer. A previous report by Ryell et al(1) detailed the results obtained up to 1978. Since then, some sections had physically deteriorated to the degree that complete resurfacing of all the test sections was warranted in 1985. Prior to this work, a final evaluation was carried out on the sections and a report is being prepared on the evaluation of the performance of these test sections after 11 years of service. The up-dated results to 1985 (Fig. 3) are summarized below :

(i) HL-1 and Modified HL-1 Mixes - Sections 7 (Fig. 4) and 9, which are considered DFC mixes (i.e. consisting of steel slag or blast furnace slag coarse and fine aggregates respectively), had maintained a F.N. (friction number, formerly skid number) in excess of 31. In comparison, section 8 containing steel slag coarse aggregate and a

blend of natural sand and limestone screenings as the fine aggregate, and section 10 with similar fine aggregate and blast furnace slag coarse aggregate exhibited significantly lower F.N.. This fine aggregates had a similar effect on the frictional properties of the HL-1 mixes containing traprock coarse aggregate particularly in the driving lane (e.g. Section 3 versus 1).
Test Sections 3 and 6 that utilized traprock screenings as the fine aggregate have F.N. just on the 31 level.

(ii) Open Graded Mixes - Test Sections 13 and 14 had maintained the high F.N. with good macrotexture appearance (Fig. 5). However, Sections 15 and 16 containing a reduced proportion of coarse aggregate had a reasonable initial F.N. but the level had declined to below the 30 value. The interconnected voids in mixes 13 and 14 appeared very efficient in removing water away from the tire to road contact area and thus enhancing the frictional characteristics as well as reducing splash and spray in wet weather. However, these voids tend to clog up after 4 to 5 years of service but the permeability is still relatively higher than the other mixes (Table 4, see also sub-section g); it appears that the pumping action of the tires helps to clean out some of the debris.

(iii) Other Mixes - The two sand mixes (11 and 12) have maintained at the level of about F.N.= 30, but these mixes are considered not quite suitable for high speed traffic due to the lack of macrotexture on the surface; the lower initial F.N. value for section 12 is because of the higher AC content used (Table 2). The mastic mix (17) had a lowest initial friction value of all the test sections and after 3 years, the values are approaching 20.

(iv) Friction Number (FN) versus speed - Fig. 6 shows that the OFC (section 13) has less drop in the FN than all the mixes compared, especially the sand mix (section 11). It is clear that the two DFC mixes consisting of slag materials (sections 7 and 9) yield the highest FN of all the mixes altough they maintain a similar friction-speed gradient as the traprock DFC mix (section 3). The dense graded mixes (sections 1 and 4) and mastic asphalt (section 17) seem to have a similar FN-speed gradient as the DFC mixes. An increase in stone content by 10% (e.g. section 4 versus 1) of the same type of aggregate tends to reduce the FN-speed gradient. The graph clearly suggests that, while the FN-speed gradient is governed by the macrotexture, the level of FN achievable at a given speed is a function of the types of aggregate used which determines the level of microtexture available in a mix.

(v) General - Almost all the mixes provided substantially better friction characteristics than the existing concrete. The mixes seem to have reached their equilibrium friction level after two or three years of service (Figs. 3 and 7). Also mixes which have a high initial friction value tend to take longer to arrive at their equilibrium (e.g. sections 7,13,and 3 versus 1). In the driving lane carrying 3700 c.v. per day, the mixes that provide F.N. above the value of 30 are :

- dense graded mixes with both coarse and fine aggregates consisting of traprock, steel slag or blast furnace slag (named Dense Friction Course, DFC).

- open graded mixes using traprock coarse and fine aggregates with high stone contents (named Open Friction Course OFC).

(f) Durability:

The durability of the sections is compared by using the "overall rating" derived from multiplying the length or the area of the appropriate distresses by the weighing factors assigned for the severity and type of distress as outlined in the " Manual for Condition Rating of Flexible Pavements " (4). Table 3 shows that sections 1, 9 and 17 have an overall rating of 57, 54 and 58 respectively whereas the other sections have an overall rating of between 25 and 37. The friction course mixes (e.g. sections 3,7,9 and 13) performed well relative to the dense graded mixes, except the section 9 which consisted of all blast furnance slag aggregate. The deterioration of section 9 was in the form of ravelling and delamination. It is because of the highly absorptive nature of the blast furnance slag aggregate that absorbs the A.C. and reduces the effective A.C. available for holding the aggregate in place as well as for adhering the mat to the existing pavement surface. The transverse crackings were reflection crackings from the underlying concrete pavement.

(g) Permeability:

Permeability tests were performed on the driving lane wheel path of each test section using the John Manville outflow permeameter (1). However, at the 11th year, the wheel track matrix of all the sections was closed up to the extend that it required much longer time (>1 hr.) to obtain a water permeability reading. Hence, cores taken from the test sections were tested in the laboratory for permeability using the air permeability method as described in the ASTM D3637.

The results (Table 4) indicate that the OFC test section (13 and 14) had a very high initial permeability but the voids closed up after 7 years of traffic compaction, reducing the permeability to about 10 ml/min (and DFC to zero ,Fig. 8). However, the air permeability of the OFC at the 11th

year on the driving lane is still relatively higher than the other mixes e.g. 10^{-8} cm versus < 10^{-9} cm respectively. In general,the lower air permeability in the driving lane confirms the believe that the traffic compaction in the driving lane wheel tracks is more than the passing lanes due to heavier traffic volume.

3.2 Policy on use of Friction Course Mixes

Based on the performance of these test mixes, a new Min[illegible] policy was introduced in 1978 governing the selection of surface [illegible] mixes for main highway facilities. The new policy specifies the use of Open Friction Course (OFC) mixes as the surface layer for urban freeways and Dense Friction Course (DFC) mixes for other heavily trafficked main highways carrying traffic in excess of 5,000 AADT per lane. The DFC mixes are also used in accident " black-spots " with lower traffic volumes. Other factors to be considered are:

-projected traffic volumes
-type and percentage of trucks -accident rate
-highway classification

Special provisions were drawn up for both the OFC (SP 311) and DFC (SP 321) mixes as illustrated in the appendix. The OFC consists of 65 to 70% coarse aggregate (retained on 4.75 mm sieve) with 30 to 35% washed screenings. Both the coarse and fine aggregates have to be obtained from the same source of traprock or steel slag.

The DFC mix consists of 55% of retained 4.75 mm sieve coarse aggregate and both coarse and fine aggregates have to be selected from the ' List of Designated Sources ' but do not have to be from the same source. The fine aggregate is unwashed screenings.

3.3 Task Force on Performance of Bituminous Friction Course

The commitment of the Ministry to construct more friction course pavements made it essential that the field performance of the new mixes be evaluated and necessary changes be made to optimize the performance. A Task Force was therefore set up with a mandate to review, determine and recommend the most suitable driving qualities of pavement, with specific emphasis on improving frictional characteristics. The Task Force activities covered the following:

- general performance
- winter performance
- frictional characteristics
- safety
- riding quality
- noise levels
- performance of zone paint
- open friction mixes in other jurisdictions
- observations
- recommendations

The Task Force evaluated eleven contracts consisting of five OFC and six DFC mixes, over a period between Feb. 1979 and July, 1981.

The following summarizes the findings of the Task Force (3) under each of the above topics:-

(a) General Performance :

On review of the contracts and observations, the pavements were considered performing satisfactorily. The OFC mix that had been placed over concrete pavement without sawing and sealing over the concrete joints showed reflection cracks that were ravelling extensively. All these cracks were routed and sealed. The reflection cracks on some of the DFC pavements on the other hand were not ravelled.

(b) Winter Performance :

Visual observations made during the 1978-79 winter showed:

-The OFC mixes seemed to provide the best frictional characteristics.

-There were no problems observed in clearing the OFC surfaces. The 'broadcasting' technique of salt application has worked quite effectively to clear up the OFC pavements.

-Ice buildup in the DFC mixes has been reported. This problem can be related to the method of spreading the deicing salt, i.e. windrowing versus a recommended 'broadcasting' application. The permeable nature of the DFC mix permits the brine solution to penetrate the pavement before the windrowed deicing salt has a chance to be spread by the traffic. It is recommended that both OFC and DFC mixes require the 'broadcasting' of deicing salts and a slightly higher application rate for winter snow and ice control.

(c) Friction Characteristics :

The Task Force monitored some 48 sites laid with the DFC and HL-1 mixes in southern Ontario. A friction survey in 1976 showed that mixes

with fine aggregate consisting predominantly of natural sand do not provide as good a friction number as mixes with screenings as fine aggregate (i.e. DFC, Fig. 9).

(d) Safety :

The wet pavement collisions before and after rehabilitation showed a reduction in accidents ranging between 42% and 81%. However, together with the improved surface texture, alignment improvement, additional lanes, longer lane change tapers, etc, have also been installed on some of these locations which would also contribute to the reduction of wet pavement accidents. In general, the use of improved friction surface has improved the accidents experienced.

(e) Riding Quality :

The results of the Mays meter readings (in inches of roughness per mile) indicate that the majority of the friction courses fall in the fair ride criteria of 80-100. Two of the contracts are in the good to excellent ride of less than 80 inches per mile.

(f) Noise Levels :

The OFC was found to be 2.1 dB(A) quieter than standard HL-1 mix based on roadside noise measurements.

(g) Performance of Zone Paint :

Monitoring of test sections in the core lane of Hwy. 401 indicates that normal mixes and open and dense friction course mixes have to receive a build-up of traffic paint in order to have a durable appearance. The traffic paint on the bituminous pavements had a minimum of 25% remaining with an average of 70%, whereas the concrete pavement adjacent to the test sections was in the order of 15% remaining, and this was mainly in the grooves. Zone paint on fresh OFC and DFC pavements appears to require the same amount of repainting as with standard surface course mixes.

Problems were encountered with adhesive backed plastic strips not sticking to the OFC mix. It would appear that this material must be placed on the hot mix prior to compaction so that both the mix and plastic strip can be rolled as one.

(h) Observations :

The contracts monitored have not shown any major problems. In addition to the above discussion, small over-asphalted areas were observed on some OFC pavements. They were caused by asphalt draining

down in the mix that was mixed too hot. This problem was eliminated by reducing the mix temperature to below 135^{0}C at discharge.

(i) Recommendations on the use of Friction Course Mixes :
The Task Force recommended that

- The Ministry should continue the policy of using the OFC and DFC mixes in surfacing urban freeways and main highways.
- Late fall paving should be avoided for OFC and DFC mixes and DFC mix should be placed in depths not less than 30 mm (1.2 in). Resurfacing should include a levelling course (particularly for DFC mixes) to reduce the chance of thin lifts and subsequent ravelling.
- OFC shoulder mix could consist of cheaper local aggregates.
- Mix temperatures as discharged into the truck at the plant between 122^{0}C (250^{0}F) and 135^{0}C (275^{0}F) (present specification has a maximum of 140^{0}C and placement within one hour of discharge) in order to avoid asphalt drainage.
- Tandem paving on multi-lane facilities should be used wherever practical to reduce joint ravelling.
- Dump boxes should be cleared after each discharge onto the paver.
- Maintenance patrolers should be informed of the whereabout and the need to broadcast deicing salts on OFC and DFC surface course mixes.

4. RESURFACING PROGRAM

Based on the performance of the Hwy. 401 test sections a hot mix overlay system consisting of a binder course 40 mm (1-1/2") in thickness followed by a surface course of 25 mm (1") in thickness of OFC was selected as the best method of rehabilitating the freeway.

The Ministry embarked on a program in 1976 to rehabilitate the 50 km bypass around Toronto, planning to have the program completed by 1995. A budget of three to five million dollars has been allowed annually for this program. The rehabilitation involves five main areas, namely:

- additional capacity
- repairs to structures
- environmental improvements
- pavement and shoulder rehabilitation
- construction staging or scheduling of the resurfacing

On other concrete pavements carrying high volume traffic, the normal resurfacing design has been as follows:

25 mm (1") Sand levelling course
50 mm (2") Open graded (porous) binder course
40 mm (1-1/2") Binder course
40 mm (1-1/2") Surface course

These concrete pavements however have been allowed to deteriorate to a point where they required more substantial treatment, whereas the rehabilitation treatment, by comparison, on the Toronto by-pass consists only of:

40 mm (1-1/2") Binder course
25 mm (1") OFC mix surface course

It can be seen that the challenge of a high volume road with many overhead clearance problems, etc., has been met with an overlay system that is far less expensive than the normal approach.

4.1 Performance of the Rehabilitation System

(a) Pavement Ride :

The placing of the new binder and OFC surface course mixes on the two contracts indicate an initial improvement in ride as determined by the Mays Meter (Table 5). It is felt that the roughness figures may be improved even more by the use of automatic screed controls with skiis on both sides of the paver when laying the hot mix binder course in the future.

(b) Surface Durability :

The surface course OFC shows a very small number of flushed areas due to over asphalting (drain down in truck boxes) and some minor winter snow plough scuffing at grade points such as crown and shoulders but, all things considered, the durability of the OFC has been exceptionally good to date.

4.2 Annual Friction Course Resurfacing Program

The general effect of the OFC mix overlay on improving the driving qualities of the Toronto by-pass has been substantial. In addition to the commitment to the overlay program on the bypass, there has been a gradual increase in tonnage being laid on freeways from 1978 to 1981 (Table 6). The steady volume of OFC and DFC mixes constructed each year confirms the commitment. The OFC and DFC mixes are specified for use on some 1500 km of main highway across the province (MTC total = 21,500 km) with most of

it in Southern Ontario. However,the tonnage is relatively small, with less than 20,000 tonnes for OFC and 100,000 tonnes for DFC, comparing to the average total hot mix of about 2.5 million tonnes used by the Ministry annually.

Generally there is a misconception of the perceived high cost due to the special single size (-3/8") washed coarse aggregate and washed screenings. Also, on the supplier's side, high stone content in the mix posts the problem of having to find an outlet for the surplus screenings. In fact, based on coverage per square metre the cost of OFC (laid at 25 mm thickness, 24 kg/m^2/10 mm) turns out to be about the same as or slightly less than the standard dense surface mix (HL-1) for medium-high traffic. When it is compared with DFC, its cost is about 35% lower (Table 7).

The aggregate used prior to 1982 for the OFC and DFC was mainly traprock. However, factors such as availaibility and good frictional characteristics of the slag aggregates (both steel and blast furnance slag) have lead to the increasing use of the slag mixes in future constructions.

5. CONCLUSIONS

OFC and DFC mixes are accepted by the Ministry as the most suitable mixtures for treatment of urban freeways and accident "black-spots" where heavy traffic volumes and a large number of commercial vehicles prevail.

The sequence of events that lead to the use of open graded friction course (OFC) and dense friction course (DFC) is as follows:

1947 - Construction of sections of Hwy. 401 By-pass
1952 - Initial construction as a four-lane divided
1963 - Reconstruction of original facility to multi-lane facility
- Widened to a twelve lane system of collector and express lanes
- Experienced marked increase in multi car wet weather accidents
1974 - Placement of 18 bituminous overlay test sections
1976 - Embarked on use of OFC and DFC in various contracts
1978 - Task Force set up to review and recommend the use of friction course mixes for future construction
- Formalize policy on use of OFC and DFC

The Task Force 's findings on friction courses are:-

a) General performance - satisfactory with ravelled joints at reflection cracks.

b) Winter performance - OFC provides the best friction properties.
- 'broadcasting' of salt should be used.

c) Friction characteristic - superior than standard dense mixes.

d) Safty -over 40% reduction in accidents before and after rehabilitation.

e) Riding quality - rated good to excellent.

f) Noise level - 2.1 dB (A) quieter than standard dense mixes.

g) Zone painting - requires the same quantity as standard dense mixes but adhesive backed strips must be rolled in when mix is hot.

h) Construction - avoid late fall paving.
- OFC shoulder mix could use cheaper local aggregates.
- discharge temperature at the plant be between 122^{0}C (250^{0}F) and 135^{0}C (275^{0}F).
- tendem paving to reduce joint ravelling.
- clear dump boxes after each discharge.

In order to be effective in improving the levels of friction, bituminous friction course mixes must contain harsh, angular fine aggregate such as traprock or slag fines and a sufficient proportion of crushed good quality coarse aggregate (50 to 70% retained 4.75 mm) to maintain the micro- and macrotexture on the travelled surface. These characteristics can be provided by the open friction course (OFC) and the dense friction course (DFC).

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TABLE 1: TRAFFIC VOLUMES AND TRUCK WEIGHTS

YEAR	AADT	G.V.W. TONNES	LEGAL AXLE WEIGHT TONNES
1963	77,000	32.0	8.6
1976	199,000	63.5	10.6

TABLE 2: BITUMINOUS MIXES, COMPOSITION AND DESIGN DATA(1)

Test Section Number	Mix Type	Mix Composition % Wt. of Aggregate Plus Filler: Coarse Agg. Ret. No. 4	Fine Agg. Pass No. 4	Filler Material	* % Ret #4	Asphalt % Wt. of Mix	Mix Characteristics: Marshall Stability	Marshall Flow	V.M.A. % Vol.	Voids % Vol.	
1	HL1	45TR	41NS		43.8	5.4	1625	10.3	16.9	2.8	L
			14LS			5.4	2614	11.6	17.5	3.7	F
2	HL1	45TR	41NS		48.2	5.4	1625	10.3	17.2	3.0	L
			14TRS			5.3	2870	13.4	15.0	0.8	F
3	HL1	45TR	55TRS		47.5	4.1	3185	16.5	12.9	1.2	L
						4.0	3407	15.3	13.5	2.0	F
4	HL1	55TR	34NS		54.1	4.8	1730	10.2	16.0	2.7	L
			11LS			4.8	3027	12.3	14.2	1.2	F
5	HL1	60TR	28NS	2ASB	58.1	5.6	1800	15.0	14.2	1.0	L
			10LS			5.7	1903	22.5	16.0	0.9	F
6	HL1	60TR	38TRS	2ASB	62.3	5.3	2190	22.7	15.2	1.0	L
						5.4	2570	18.7	18.6	3.4	F
7	Mod. HL1	45SL	55SLS		46.8	5.3	3520	16.0	18.5	2.7	L
						5.2	3640	13.2	18.7	3.3	F
8	Mod. HL1	50SL	38NS		47.1	5.7	2160	12.9	17.3	2.3	L
			12LS			5.7	2990	13.7	17.7	1.9	F
9	Mod. HL1	45BF	55BFS		43.2	8.0	2830	12.8	24.0	6.9	L
						7.8	3326	14.9	23.1	6.1	F
10	Mod. HL1	40BF	45NS		40.5	6.8	1975	10.4	17.9	2.9	L
			15LS			6.5	3155	9.7	17.0	2.2	F
11	Sand Mix	14TR	84TRS	2ASB	5.4	7.1	2084	27.2	17.7	0	L
						7.0	2175	40.2	19.5	0.2	F
12	Sand Mix	9TR	89TRS	2ASB	6.9	7.0	2650	19.2	16.8	0	L
						7.2	1885	45.1	20.7	1.1	F
13	Open Graded	67TR	33TRS		80.5	5.9	1458	12.7	20.6	4.7	F
14	Open Graded	67TR	31TRS	2ASB	71.7	5.8	1691	11.9	19.6	4.0	F
15	Open Graded	30TR	70TRS		29.3	5.6	2678	19.2	16.3	0.7	F
16	Open Graded	30TR	68TRS	2ASB	31.4	6.6	2116	30.5	18.6	0.2	F
17	Mastic	70TR	19TRS	9MF 2ASB	75.2	7.5	1887	56.7	21.0	1.0	F
**1-19	HL1	45TR	41NS		47.4	5.4	1625	10.3	16.9	2.8	L
			14LS			5.4	2825	14.5	14.6	0.4	F

* Based on field laboratory extraction tests.

** As Test Section 1 but constructed over a 38 mm (1½") thick bituminous base course layer.

LEGEND

Coarse Aggregate
TR - Traprock
SL - Steel Slag
BF - Blast furnace Slag

Fine Aggregate
SLS - Steel Slag Screenings
LS - Limestone Screenings
TRS - Traprock Screenings
BFS - Blast Furnace Screenings
NS - Natural Sand (Glacial Deposit)

Filler Material
ASB - Short Fiber Asbestos
MF - Mineral, Filler (Finely Crushed Limestone)
L - Laboratory Mix Designs
F - Field Laboratory Tests

Table 3: Durability Performance of Test Sections

Section	Cracks		Rav.	Patc.	Del.	Rut	Overall Rating
	Tr.	Lg.					
1	4	44	6	0	0	3	57
3	0	1	18	6	4	3	32
4	12	4	6	0	0	3	25
7	16	2	6	9	1	3	37
9	5	7	18	6	14	5	54
11	34	0	0	0	2	0	36
13	6	2	6	14	5	0	33
17	26	5	18	8	2	0	58

Table 4: Permeability Results

Section	Water Permeability (ml/min)				Air Permeability @ 11 yr (cm)		
	Age (year)				Passing Lane	Centre Lane	Driving Lane
	0	2	5	7			
1	-	1.1	0	0	.imp	.imp	8.6E-12
2	-	1.7	-	0	.imp	.imp	2.2E-11
3	70	3.2	2.5	0	6.6E-10	1.3E-9	1.9E-9
4	-	1.2	-	0	.imp	.imp	.imp
5	-	1.9	-	0	6.4E-10	.imp	.imp
6	-	50	-	3	3.0E-9	6.0E-9	1.3E-9
7	-	4	0	0	10.0E-10	2.6E-10	3.2E-11
8	-	4	-	0	.imp	.imp	.imp
9	vh	30	5.5	0	1.9E-9	2.4E-9	1.5E-10
10	22	2	-	0	.imp	.imp	.imp
11	-	2.8	-	0	1.6E-9	.imp	7.1E-11
12	-	2.4	-	0	6.6E-11	3.1E-11	-.-----
13	vh	78	20	7	1.3E-9	1.3E-10	-.-----
14	vh	150	-	13.5	6.6E-9	1.2E-9	1.0E-8
15	6	3	-	0	6.7E-12	.imp	.imp
16	22	2.5	-	0	1.4E-10	.imp	.imp
17	-	4.3	-	0	.imp	.imp	1.0E-9
18	-	2.4	-	0	3.4E-11	.imp	.imp

- = results not available, vh = very high permeability,
imp = impermeable, E = x10^{-}

Table 5: Roughness Measurement By Mays Ride Meter

Contract Number	Original			New			Change		
	$\bar{x}$	σ	n	$\bar{x}$	σ	n	$\bar{x}$	σ	n
1	110	24	5	73	3	5	-38	17	5
2	141	19	7	72	14	7	-70	14	7

Table 6: Annual Volume of Friction Course Mixes (tonnes)

YEAR	OFC	DFC
1976	5,080	27,400
1977	40,130	104,800
1978	11,098	104,800
1979	8,147	129,271
1980	7,357	113,698
1981	50,108	112,708
1982	10,531	73,096
1983	18,371	43,829
1984	36,213	76,488
1985	11,138	95,186
Total	198,173	881,276

Table 7: Comparative Cost (1983) of Friction Course Mixes (OFC and DFC) and Standard Mix (HL-1) (1986 cost about $1.50 /tonne higher)

Unit	Cost ($CN)				% above/below HL-1		
	HL-1	DFC	OFC	OFC	DFC	OFC	OFC
cm	40	40	40	25	40	40	25
Tonne	34.00	42.00	50.00	50.00	24	47	47
m^2	3.50	4.30	5.15	3.20	23	47	-9

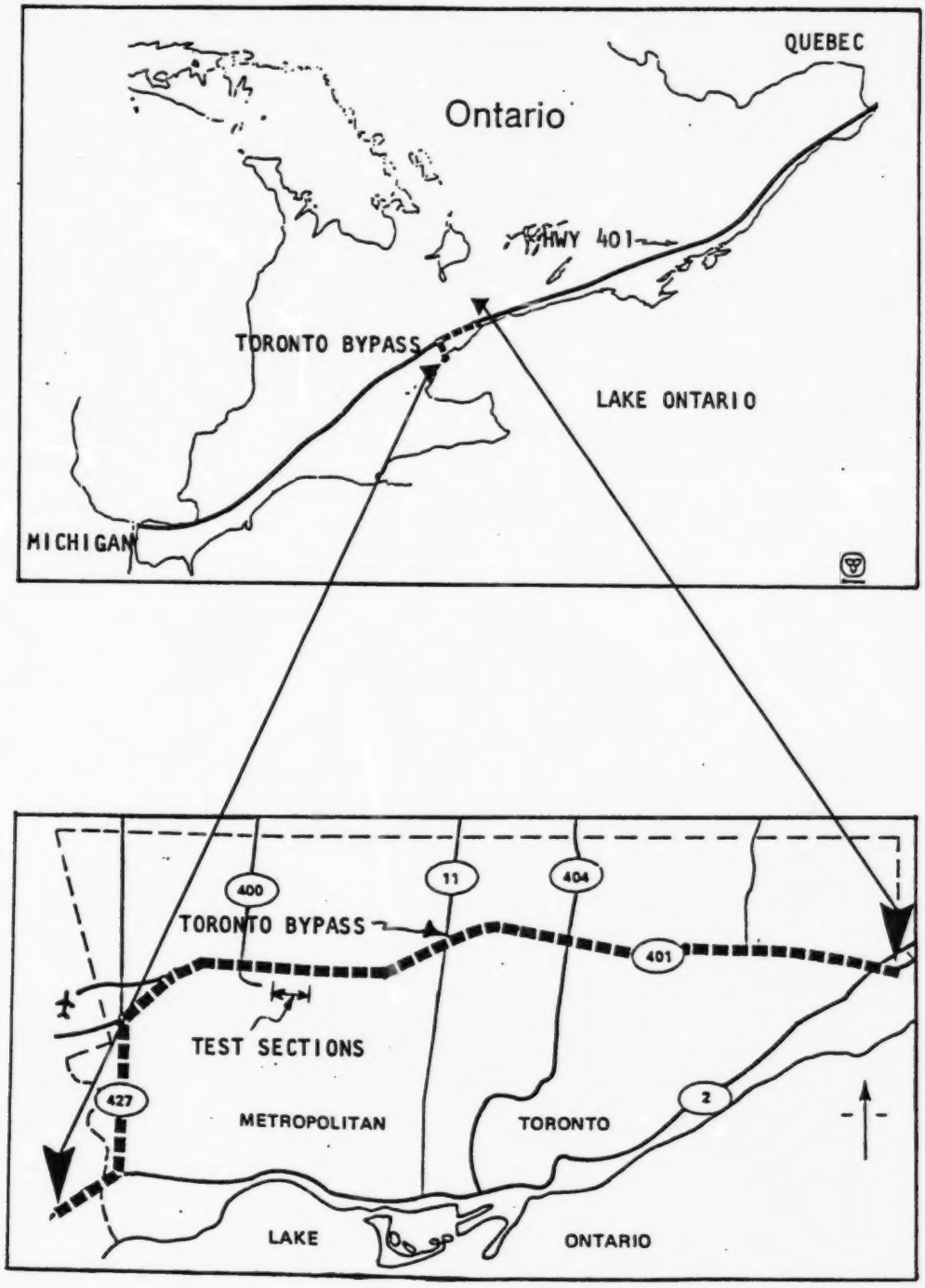
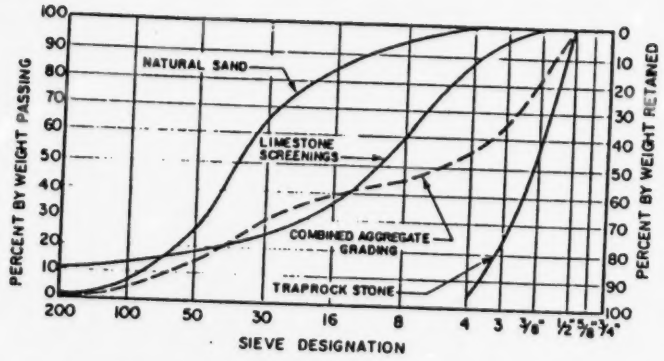
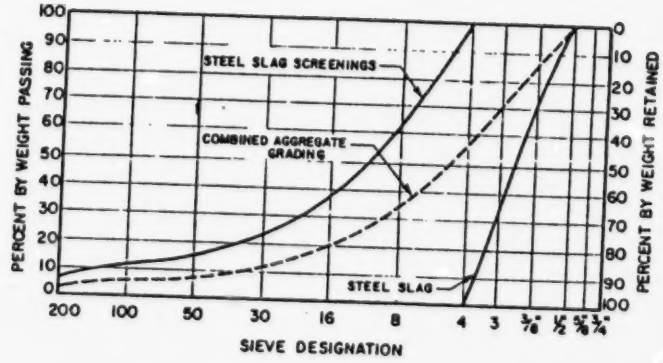


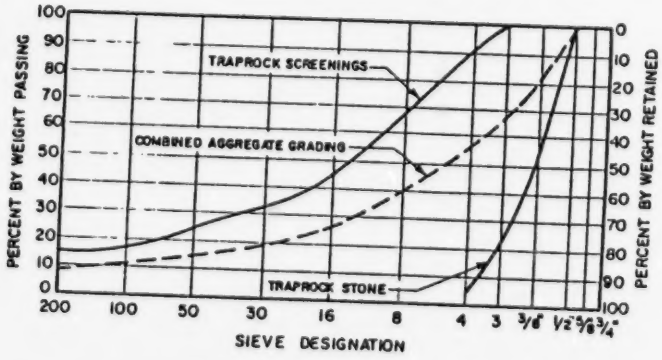
FIG. 1: THE TORONTO BY-PASS, HWY. 401 AND LOCATION OF TEST SECTIONS



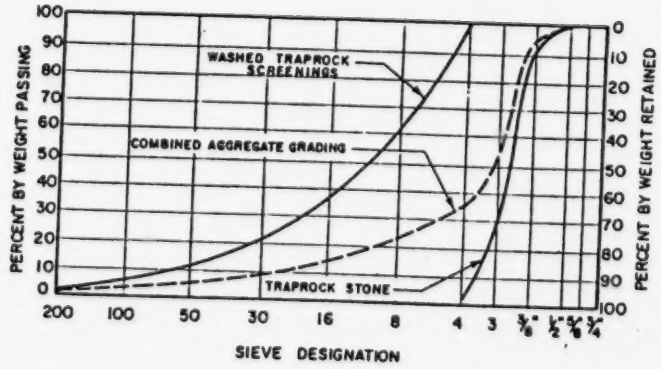
Aggregate Gradations, Test Section No. 1



Aggregate Gradations, Test Section No. 7



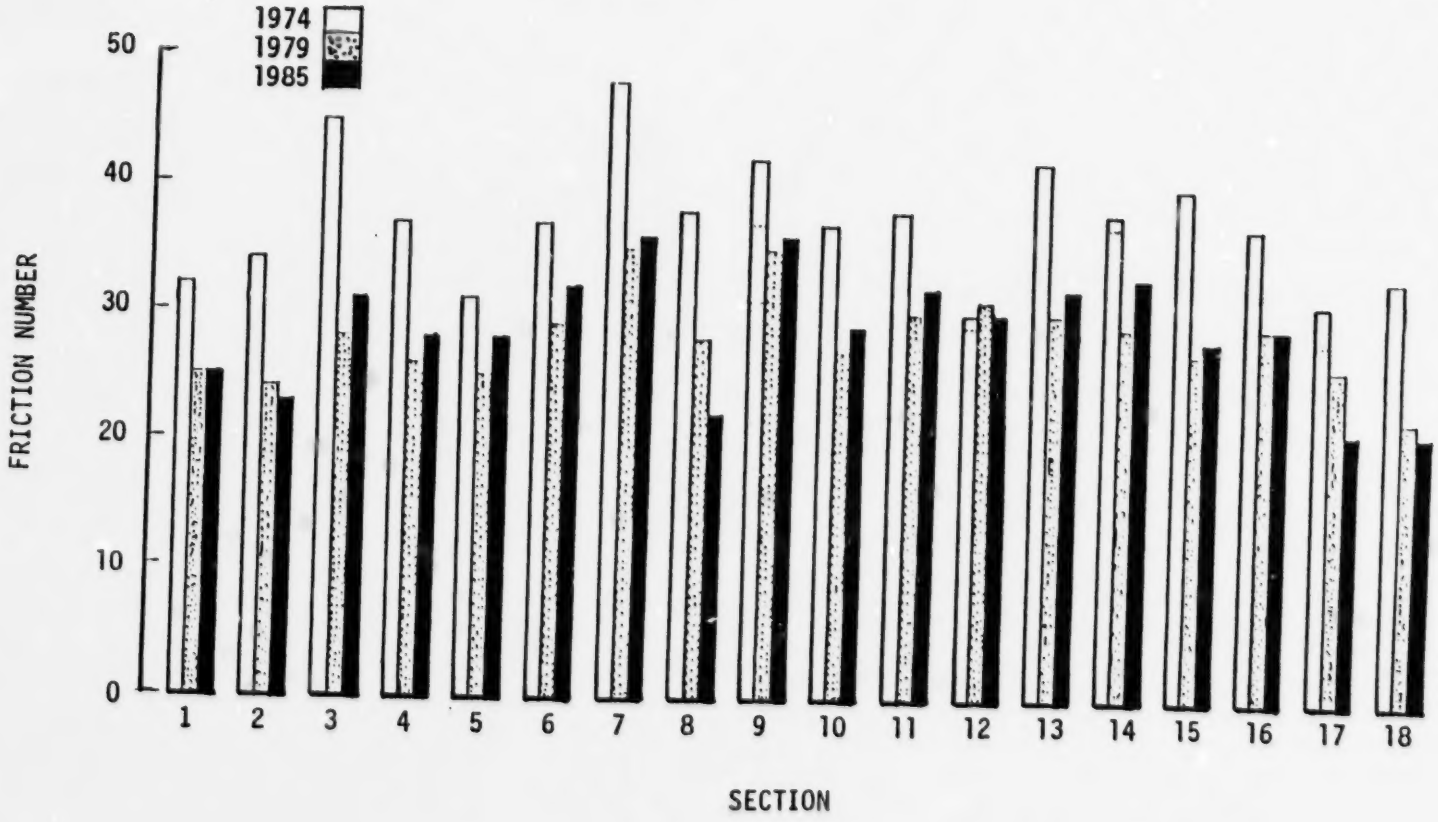
Aggregate Gradations, Test Section No. 3



Aggregate Gradations, Test Section No. 13

FIG. 2: GRADATIONS OF FOUR OF THE TRIAL MIXES (1)

FIG. 3: FRICTION NUMBER (AT 100 KM/H) OF DIFFERENT TEST SECTIONS ON THE DRIVING LANE



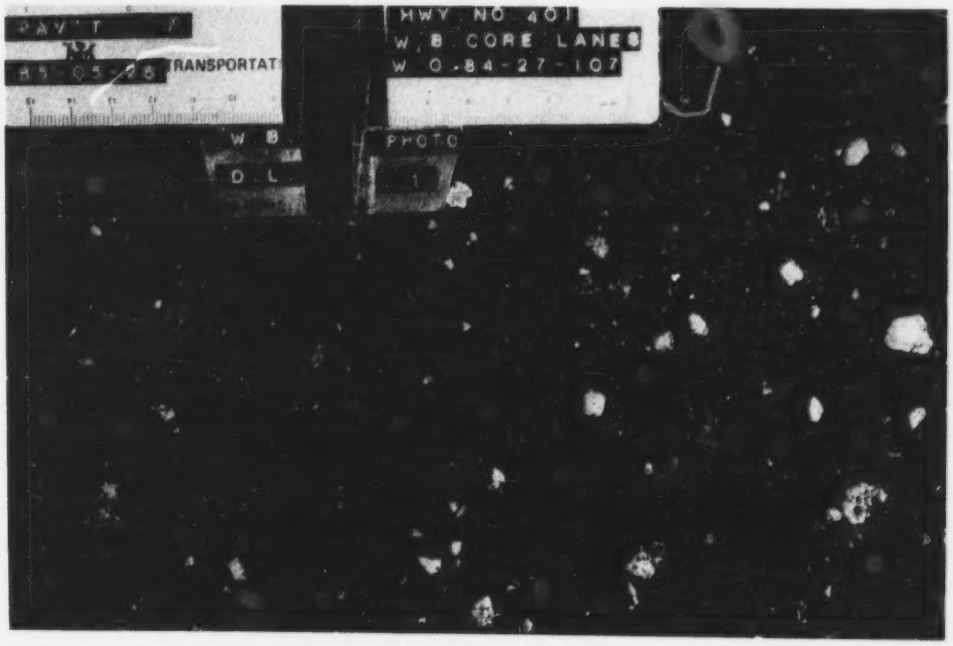


Fig. 4: Close-up of Test Section No. 7, Wheel Path, Driving Lane, After 11 Years Service

Friction Excellent, Good Macrotexture and Microtexture

Steel Slag Coarse Aggregate
Steel Slag Screenings Fine Aggregate

Fig. 5: Close-up of Test Section No. 13, Wheel Path, Driving Lane, After 11 Years Service

Friction Excellent,
Well Developed Macrotexture

Traprock Stone Coarse Aggregate
Traprock Screenings Fine Aggregate

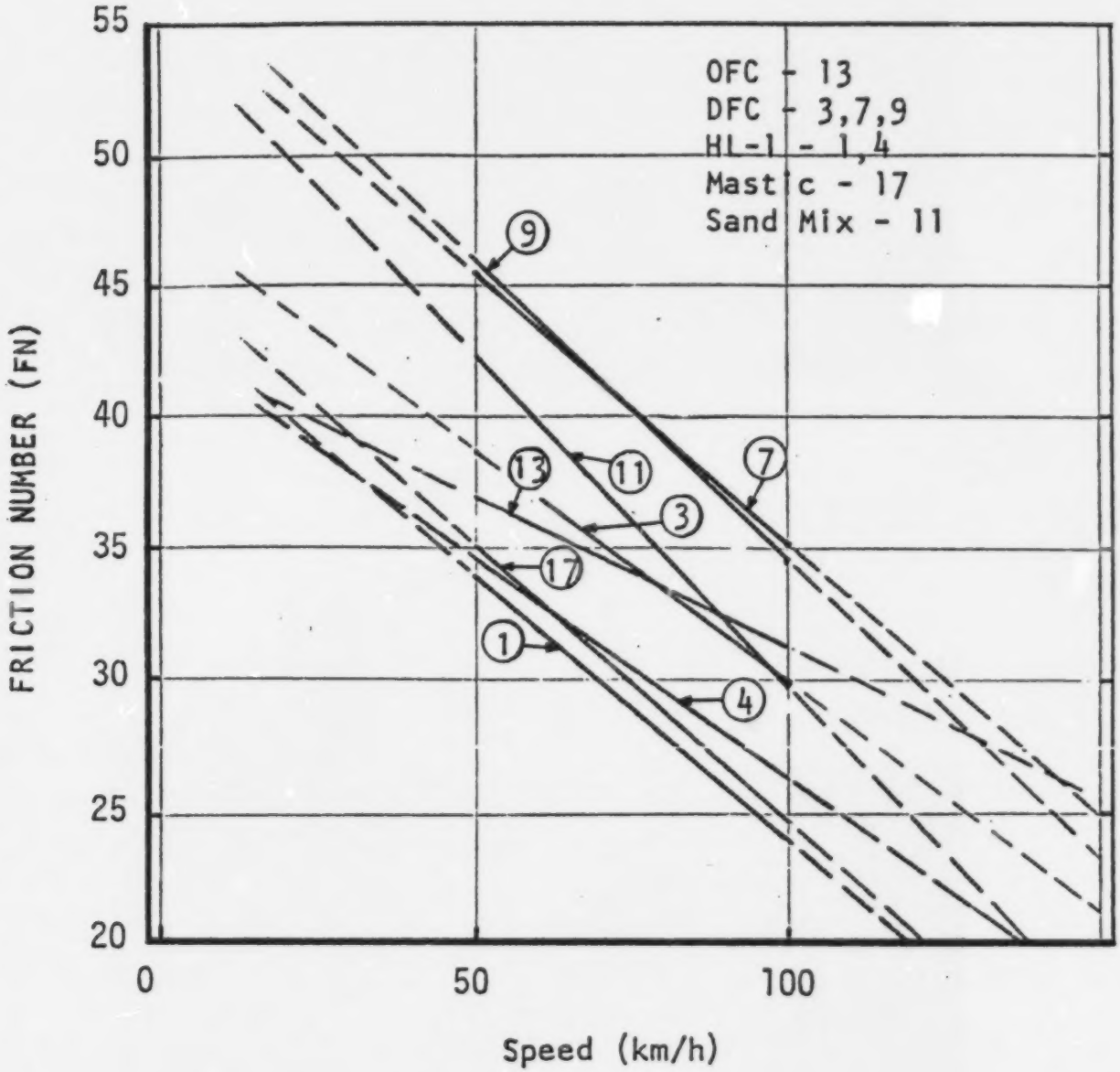


FIG. 6: INFLUENCE OF SPEED ON THE FRICTION NUMBER FOR DIFFERENT MIXES WITH VARIOUS DEGREES OF MACROTEXTURE (AFTER 11 YEARS OF SERVICE)

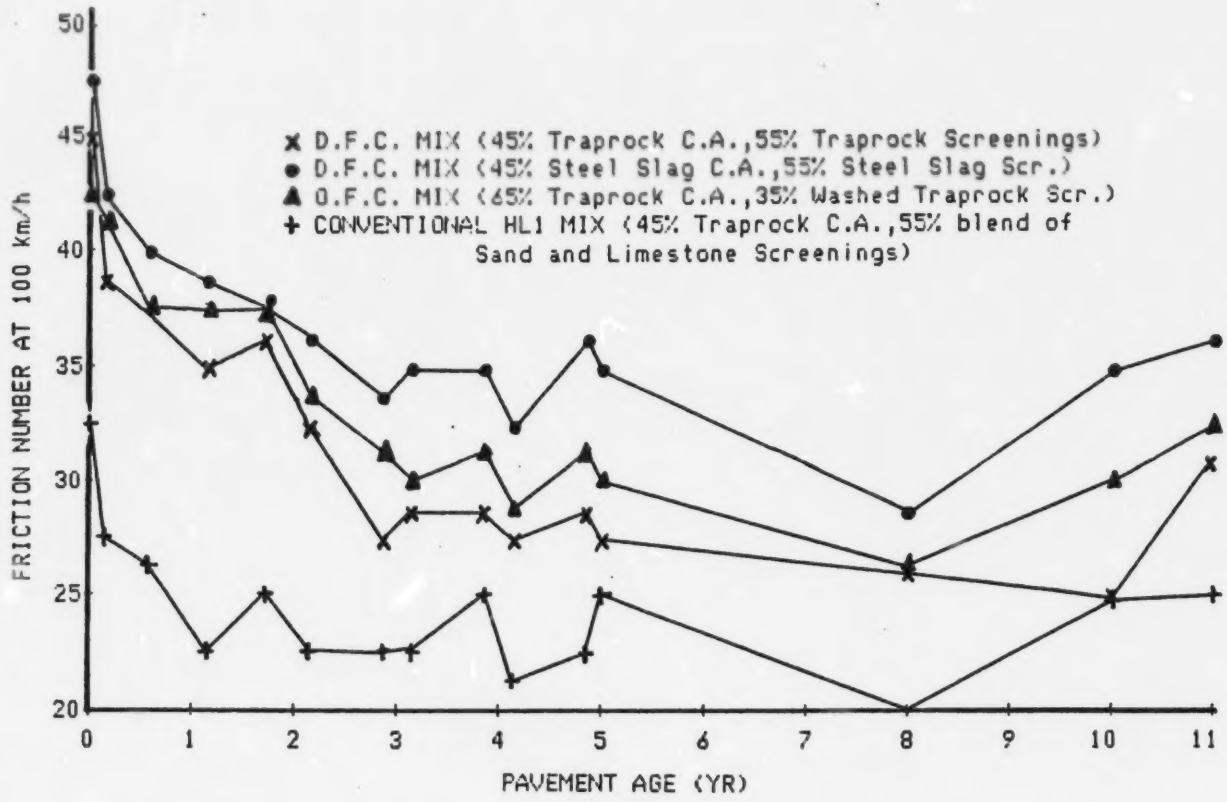
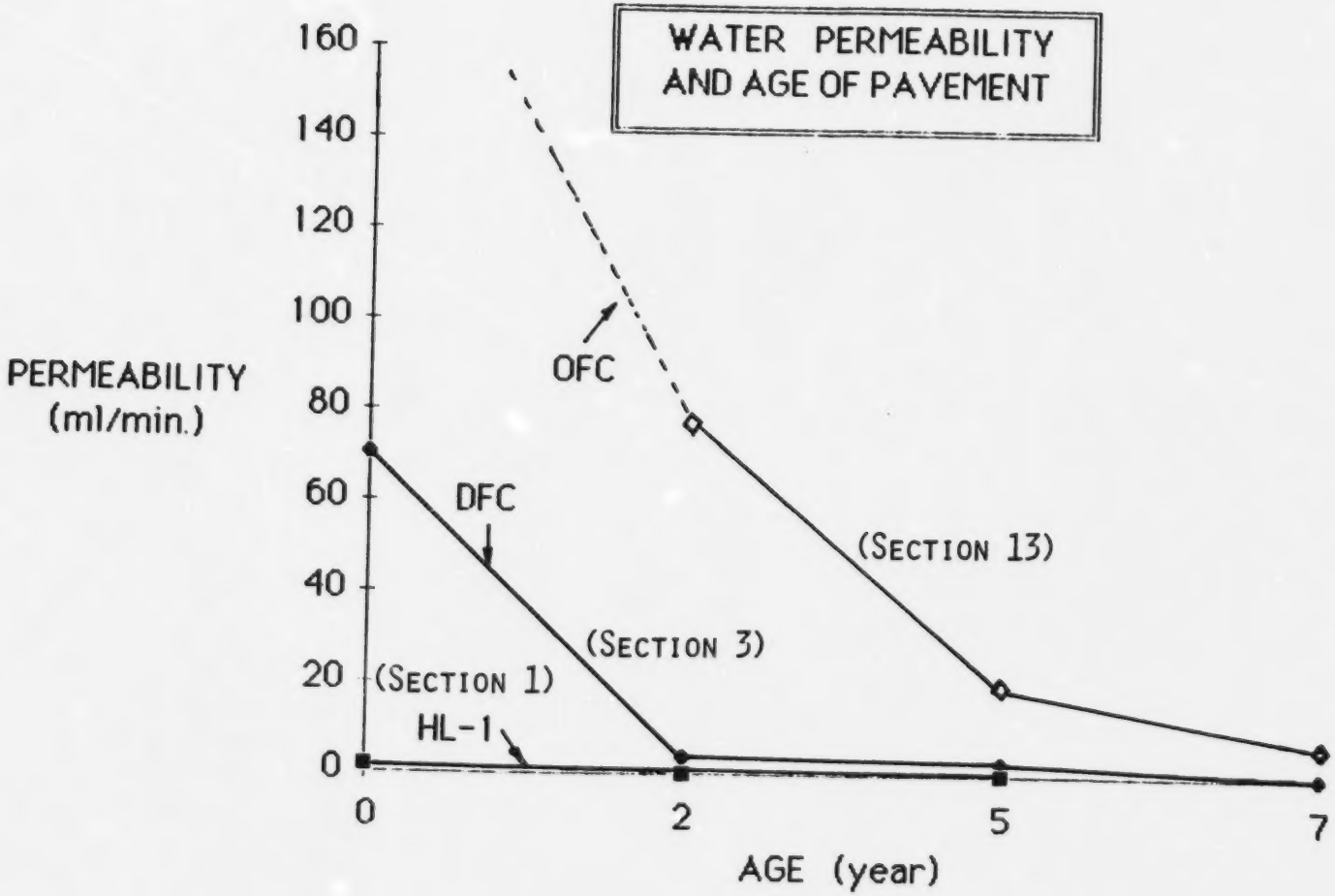


FIG. 7: CHANGE IN FRICTION NUMBER WITH TIME FOR SELECTED TEST SECTIONS

FIG. 8


WATER PERMEABILITY
AND AGE OF PAVEMENT
PERMEABILITY
(ml/min.)
160
140
120
100
80
60
40
20
0
OFC
DFC
(SECTION 13)
(SECTION 3)
(SECTION 1)
HL-1
0
2
5
7
AGE (year)

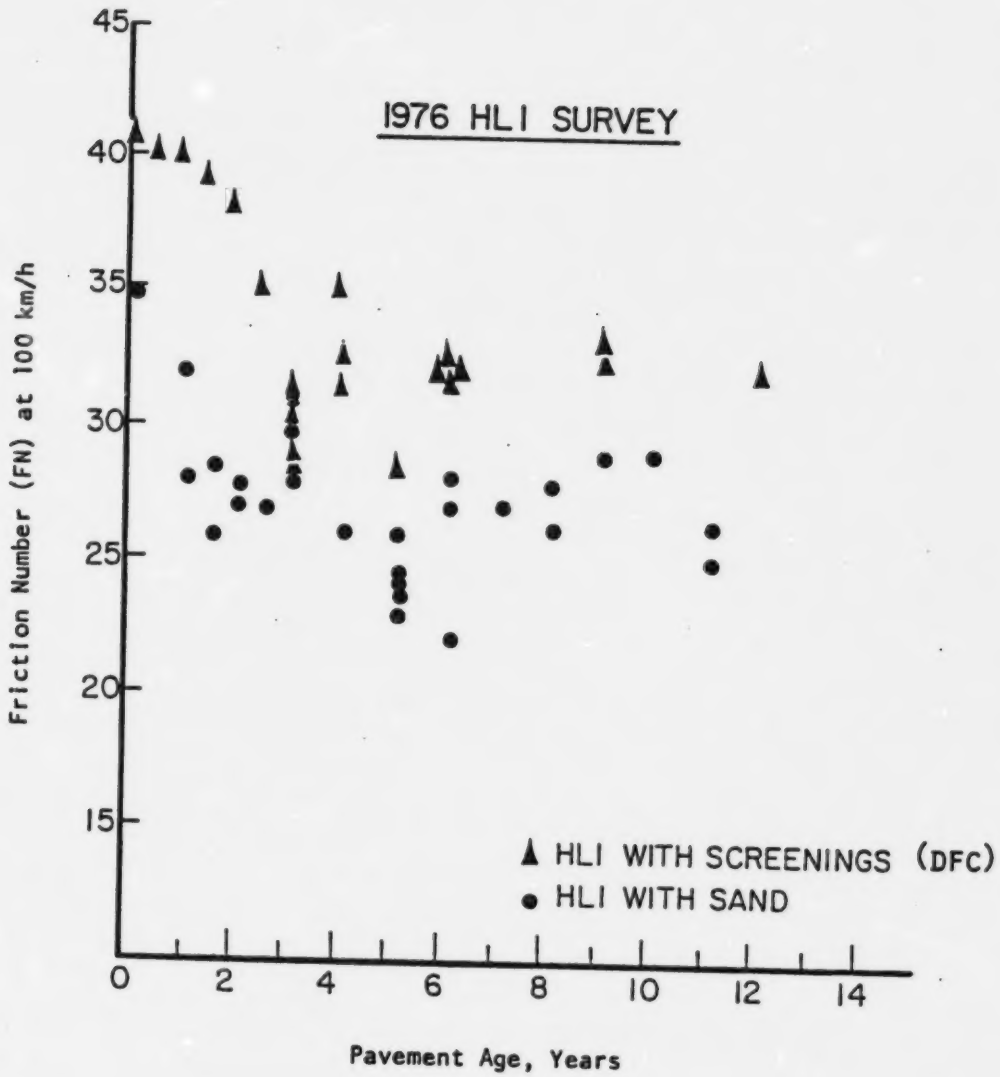


FIG. 9: FRICTION SURVEY OF HL-1 MIXES LAID IN SOUTHERN ONTARIO

APPENDIX

OPEN FRICTION COURSE MIX - Item No.

Description

This special provision covers the requirements for open friction course (O.F.C.) mix.

General Requirements

Open friction course mix shall meet the requirements for HL 1 as specified in OPSS 310 except as otherwise stated in this special provision.

Materials

Aggregates

The fine aggregate shall be washed screenings. The raw material or coarse and fine aggregates shall be obtained from sources listed on the Supplementary Aggregate Sources List for Open Friction Course Mix. The coarse and fine aggregates shall be obtained from the same source and they shall meet the following gradation requirements:

Coarse Aggregate

M.T.C. Sieve Designation	Percentage Passing
13.2 mm	100
11.2 mm	95 - 100
9.5 mm	85 - 100
6.7 mm	20 - 50
4.75 mm	0 - 15
75 µm	0 - 2 (0 - 1 for gravel)

Fine Aggregate

M.T.C. Sieve Designation	Percentage Passing
9.5 mm	100
4.75 mm	85 - 100
2.36 mm	50 - 70
1.18 mm	25 - 45
600 µm	10 - 30
300 µm	10 - 20
150 µm	0 - 10
75 µm	0 - 3

Physical Requirements for Coarse Aggregate

Steel slag shall not be required to met the Absorption by Weight and Petrographic Number requirements of Table 3, OPSS 1003.

The total amount of non-slag constituents, such as furnace brick, incompletely fused fragments, lime, wood, rock, etc., in steel slag shall not be more than 3 percent by mass and the wood content alone shall not be more than 0.5 percent by mass.

Mix Proportions

The approximate coarse and fine aggregate proportions by mass for the open friction course mix are:

65% - 70% retained on 4.75 mm sieve
30% - 35% passing 4.75 mm sieve

The actual proportions shall be determined by mix design. The quantity of asphalt cement required is determined by multiplying the A.C. content specified in the contract by the actual mass of the open friction course mix placed.

The approximate asphalt cement contents and field densities for various aggregates experienced by the M.T.C. are as follows:

Origin of Raw Material For Aggregates	% A.C. (By Mass)	Approx. Density Kg/m^2/10mm Thickness or 90% of Laboratory Marshall Density
Gravel	5.3	21.2
Quarried Trap Rock	5.0	23.0
Steel Slag	5.2	25.5

Mix Distribution

The tonnage shown in the tender is based on a combination of traprock coarse and fine aggregates. If steel slag or gravel aggregates are used, the tonnage of actual mix placed shall be adjusted for density difference so that the specified course thickness is maintained.

Mix Production

The mix shall be produced in a batch plant.

Hot Mix Storage Bins

The use of hot mix storage bins for storing this mix shall not be permitted.

Pavers

All pavers shall be equipped with either tamper bars or vibratory screeds.

Construction

Preparation and Placement of the Mixture

If the mixing plant is equipped with a dust collector system which discharges directly into the boot of the hot elevator, such a system shall be purged of any fines accumulated from other previous production, before any open friction course mix (OFC) is manufactured. This procedure will take approximately two (2) hours to complete.

The temperature of the OFC mix, at discharge from the asphalt plant, shall not exceed 140° C.

The OFC mix shall be placed within one hour of discharge from the asphalt plant.

The air temperature for placement of OFC shall be 12° C minimum.

The Contractor shall provide an on-site dump area where, at the direction of the Authority Inspector, vehicle boxes shall be cleaned of all deleterious material immediately after the discharge of OFC.

Sampling and Testing

The Contractor shall demonstrate his ability to produce the desired mix before the initial placement of surface course on the contract. This shall be done at the plant by sampling and testing from a minimum of two batches of the size which will be used. Testing will take approximately two hours. After the testing period, the Contractor may start placing the mix on the road providing the test mix is satisfactory. If the test mix is unsatisfactory, corrections shall be made and the testing procedure repeated.

Trial Area

A surface course trial area will not be required for the open friction course.

Compaction of Mixture

Compaction of the mix shall be with steel-tired rollers only. Two 9-11 t steel-tired rollers shall be provided for each paver in use. Compaction shall be carried out immediately after the mixture is placed due to rapid cooling of the mixture.

Requirements for Completed Pavement Courses

Temporary Ramps

At the end of each completed portion, prior to opening of the lanes to traffic, the completed sections of the bituminous surfacing shall be ramped down to the existing pavement at a slope of 25 mm in 3 m.

The material to be used for construction of the ramps shall be as determined on the site by the Engineer.

In all cases, the transition shall not form part of the permanent pavement

but shall be removed before the paving of the adjacent section.

Measurement for Payment

The payment quantities indicated on the tender are based on mixes consisting of traprock aggregates only. The quantity for payment for steel slag and gravel O.F.C. mix incorporated into the work shall be determined by multiplying the total measured mass of O.F.C. mix with the appropriate factor given in the table below:

Origin of Raw Material for Aggregates	Multiplying Factor
Gravel	1.09
Quarried Trap Rock	1.00
Steel Slag	0.90

DENSE FRICTION COURSE MIX - Item No

Dense friction course mix shall meet the requirements of HL 1 as specified in OPSS 310 except as follows:

Aggregates

The coarse and fine aggregates shall be obtained from the trap - rock or slag sources on the List of Designated Sources for HL-1 coarse aggregate. The coarse aggregate shall meet the requirements for HL-1 and the fine aggregate shall be unwashed. The coarse and fine aggregates do not have to be obtained from the same source.

Asphalt Cement

a) Supply: - When the Authority supplies asphalt cement, the Authority will supply up to 4.5% asphalt cement (by mass) for the equivalent tonneage of trap - rock mix; the Contractor shall supply any additional asphalt cement required, depending on the aggregate selected by the Contractor, up to the percentage shown below for the aggregate combination utilized. The Authority will provide any asphalt cement required beyond the percentage shown for the combination utilized.

b) Content: - Regardless of the type of aggregates used, the quantity of asphalt cement required is determined by multiplying the A.C. content specified in the mix design by the actual mass of the dense friction course mix placed.

Mix Proportions and Characteristics

The approximate coarse and fine aggregate proportions (by volume) for the dense friction course mix are:

Retained 4.75 mm sieve 55%
Passing 4.75 mm sieve 45%

The approximate asphalt cement content and density for the various combinations of aggregates experienced by the Authority are as follows:

Coarse Aggregate	Fine Aggregate	% A.C. (By Mass)	Approx. Density kg/m²/10mm Thickness @ 96% of Laboratory Marshall Density
Trap Rock	Trap Rock	4.5	27.0
Trap Rock	Steel Slag	5.4	28.0
Trap Rock	Blast Furnace Slag	6.0	24.3
Steel Slag	Steel Slag	5.7	28.5
Steel Slag	Trap Rock	5.1	28.0
Steel Slag	Blast Furnace Slag	6.1	26.0
Blast Furnace Slag	Blast Furnace Slag	8.6	21.3
Blast Furnace Slag	Steel Slag	7.0	24.4
Blast Furnace Slag	Trap Rock	5.3	23.2

The actual mix proportions, asphalt cement content and density, shall be determined by mix design. The Marshall void content of the mix shall be set at 2.5%.

Mix Distribution

The tonneage shown in the tender is based on a combination of 55% trap-rock coarse and 45% trap-rock fine aggregate (by volume). If other aggregate types and combinations are used, the tonneage of actual mix placed shall be adjusted for the density difference so that the specified course thickness is maintained.

Sampling and Testing

The contractor shall demonstrate his ability to produce the desired mix before the initial placement of surface course on the contract. This shall be done at the plant by sampling and testing from a minimum of 2 batches of the size which will be used. Testing will take approximately two hours. After the testing period, the Contractor may start placing the mix on the road providing the test mix is satisfactory. If the test mix is unsatisfactory, corrections shall be made and the testing procedure repeated.

Trial Area

A surface course trial area will not be required for the dense friction course.

Measurement for Payment

The payment quantities indicated on the tender are based on the mixes consisting of trap rock aggregates only. The quantity for payment shall be determined by multiplying the total measured mass of the dense friction course mix incorporated into the work by the appropriate factor given in Table 1 below, depending on the aggregate combination supplied.

Coarse Aggregate	Fine Aggregate	Multiplying Factor
Trap Rock	Trap Rock	1
Trap Rock	Steel Slag	0.97
Trap Rock	Blast Furnace Slag	1.11
Steel Slag	Steel Slag	0.95
Steel Slag	Trap Rock	0.98
Steel Slag	Blast Furnace Slag	1.04
Blast Furnace Slag	Blast Furnace Slag	1.27
Blast Furnace Slag	Steel Slag	1.11
Blast Furnace Slag	Trap Rock	1.16

Warrant: Always with this tender item.